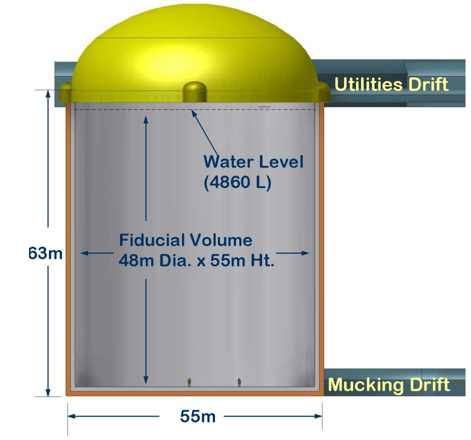
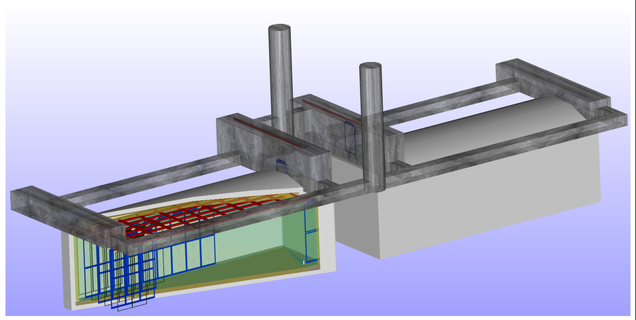


Status of LBNE

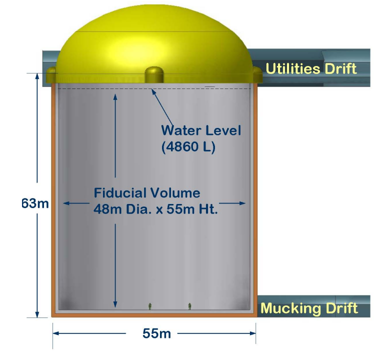
Milind Diwan for LBNE collaboration

12/9/2011, PAC FNAL

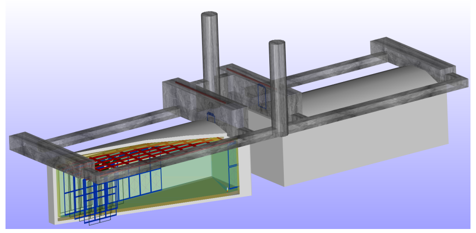
BROOKHAVEN NATIONAL LABORATORY



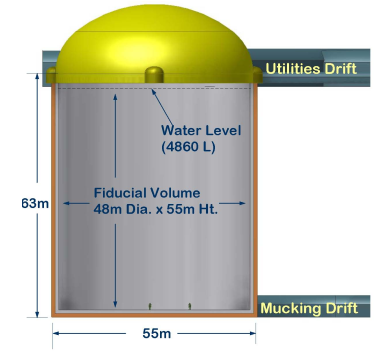
Outline



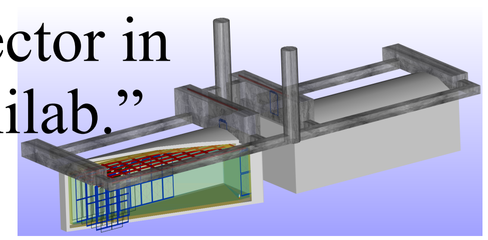
- Organization
- Technology choice process
- Summary of recent milestones
- Scientific progress
  - Technical progress/simulations



Long sustained effort towards CP violation in neutrinos



- Letter of Intent 2002, **Neutrino Oscillation Experiments for Precise Measurements of Oscillation Parameters and Search for numu->nue Appearance and CP Violation, Hep-ex/0205040**
- BNL-69395 (2002), 71228 (2003), 73210(2004), **Phys.Rev.D68:012002,2003**.
- Proposal in 2006: Proposal for an Experimental Program in Neutrino Physics and Proton Decay in the Homestake Laboratory: BNL-76798-2006-IR, hep-ex/0608023
- "The program we propose will benefit from a beam from FNAL because of the high intensities currently available from the Main Injector with modest upgrades. The possibility of tuning the primary proton energy over a large range from 30 to 120 GeV also adds considerable flexibility to the program from FNAL."
- Proposal was reviewed by BNL PAC: recommended that we work with FNAL.
- 2008 - P5 report "The panel recommends a world-class neutrino program as a core component of the US program, with the long-term vision of a large detector in the proposed DUSEL laboratory and a high-intensity neutrino source at Fermilab."



Long-Baseline Neutrino Experiment Collaboration

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Brookhaven: M. Bishai, R. Brown, H. Chen, M. Diwan, J. Dolph, G. Geronimo, R. Gill, R. Hackenberg, R. Hahn, S. Hans, D. Jaffe, S. Junnarkar, J.S. Kettell, F. Lanni, Y. Li, L. Littenberg, J. Ling, D. Makowiecki, W. Marciano, W. Morse, Z. Parsa, C. Pearson, V. Radeka, S. Rescia, T. Russo, N. Samios,R. Sharma, N. Simos, J. Sondericker, J. Stewart, H. Tanaka, C. Thorn, B. Viren, Z. Wang, S. White, E. Worcester, M. Yeh, B. Yu, C. Zhang

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Dakota State: B. Szcerbinska

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Irvine: G. Carminati, W. Kropp, M. Smy, H. Sobel

Kansas State: T. Bolton, G. Horton-Smith

LBL: B. Fujikawa, V.M. Gehman, R. Kadel, D. Taylor

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Pennsylvania: S. Grullon, J. Klein, K. Lande, T. Latorre, A. Mann, M. Newcomer, S. Seibert, R. vanBerg

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Rochester: L. Loiacono, K. McFarland

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South Carolina: H. Duyang, B. Mercurio, S. Mishra, R. Petti, C. Rosenfeld, X Tian

South Dakota State: B. Bleakley, K. McTaggert

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Texas: S. Kopp, K. Lang, R. Mehdiyev

Tufts: H. Gallagher, T. Kafka, W. Mann, J. Schnepps

UCLA: K. Arisaka, D. Cline, K. Lee, Y. Meng, F. Sergiampietri, H. Wang

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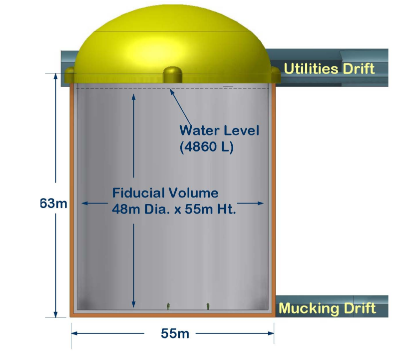
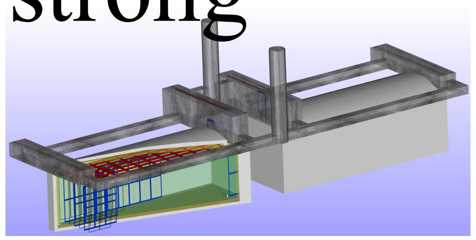
Yale: E. Church, B. Fleming, R. Guenette, K. Partyka, J. Spitz, A. Szelc

23 November 2011 (324)

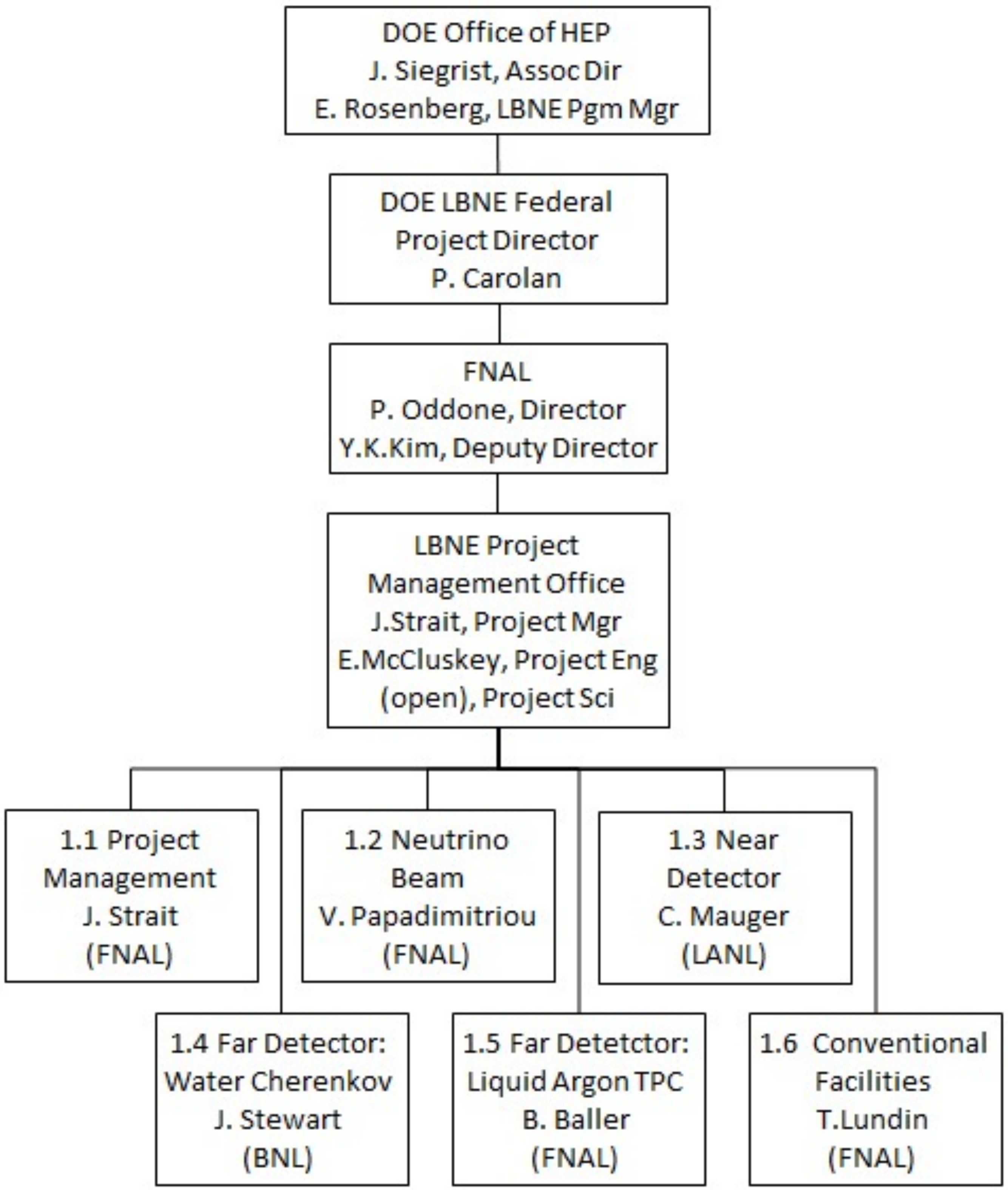
Collaboration



- Collaboration has 60 institutions from 25 states, 5 countries, >300 members.
- Beginnings of international collaborators.
- All important collaboration committees have been organized and working well. Institutional Board meeting regularly.
- Executive Committee has been meeting regularly (every 2 weeks for 2 years).
- Large fraction of the collaboration has never worked at FNAL or are coming back after a long absence.
- LBNE collaboration with its breadth intends to be a strong asset for FNAL for the future.



LBNE Project Organization



- Fermilab is the Lead Lab, and is responsible for the Beam and LAr Detector
- BNL is responsible for the Water Cherenkov Detector
- LANL is responsible for the Near Detector
- The Project and Collaboration are well integrated:
  - Collaboration is heavily involved in Project planning.
  - Project leadership are members of the Collaboration Exec Committee.
  - Spokespeople are members of the Project Management Board.

Far detector Technology Choice: A Deliberate and Comprehensive Process

- January 2010: Physics Working Group (PWG) established
- August 2010: PWG/Community Summer Workshop on LBNE at the INT in Seattle. Interim report released (final version now posted at ArXiv: 1110.6249v1) with evaluation of **14 possible far detector configurations**

PWG Established at January 2010
LBNE Collaboration Meeting

Working Group Organization

Far Detector Simulations Groups (WCh and Lar)

These groups will continue to operate as they do now, responding to requests from the project to develop detector designs for the far detectors. Need BEAM AND ND GROUPS (combined?)

These groups need to collaborate with Project Management to come up with "physics reference detector". E.g., particle ID, energy resolution. This list should be vetted via a suitable process. SIMPLE LIST IS NEEDED.

Justification for each number (measured, extrapolated, simulated) plus estimated uncertainty.

Physics Working Group

Organized via PHYSICS TOPICS

Will evaluate:

1. Potential scientific impact
2. Evaluation of sensitivity for reference physics configurations
3. Enumeration of potential risks

Basic principles for PWG also established

Process

- Topical groups MUST be technology independent as far as participants. They need to consider technology performance, but should not be technology advocacy groups.
- Groups formed within next two weeks. Leader appointed by spokespersons (consultation with EC).
- Reference configurations/parameters approved by EC by February.
- Reports from PWG at May meeting. Interim status reports to EC on regular basis
- Final reports by end of August
- EC retreat – presentation to Collaboration at September meeting

August 2010 Report of the PWG

LBNE-PWG-002 (Rel. 0.0)

The Physics Potential for a Comprehensive Set of Beam, Near Detector and Far Detector Configurations of the Long-Baseline Neutrino Experiment Project

M. Bass,[3] M. Bishai,[2,*] E. Blaufuss,[14,*] R. Carr,[4] M. Diwan,[2] S. Dye,[13] B. Fleming,[21] H. Gallagher,[10,*] G. Garvey,[9] R. Guenette,[21] D. Jaffe,[2] E. Kearns,[1,*] S. Kettell,[2] J. Link,[20] W. Louis,[9] S. Mishra,[17] D. Mohapatra,[20] V. Paolone,[16] R. Petti,[17,*] J. Raaf,[1] D. Reitzner,[6] K. Scholberg,[5,*] M. Shaevitz,[4] M. Smy,[12,*] R. Svoboda,[11] R. Tayloe,[7] N. Tolich,[18,*] M. Vagins,[8,*] B. Viren,[2] L. Whitehead,[2] R.J. Wilson,[3,†] G. Zeller,[6] and R. Zwaska[6]
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A. Beck,[22] O. Benhar,[23] F. Beroz,[5] A. Dighe,[24] H. Duan,[25] A. Friedland,[26] D. Gorbunov,[27] P. Huber,[28] W. Johnson,[29] J. Kneller,[30] J. Kopp,[31] C. Lunardini,[32] W. Melnitchouk,[33] A. Moss,[34] M. Shaposhnikov,[35] and D. Webber[19]
(Additional Contributors)

#	Detector configuration	LBP	PDK		SNB	SRN	Atm	Sol
			$e\pi$	$K\nu$				
1	Three 100 kt WC, 15%	A1	C2	D4	B3	D4	B1	D3
1a	Three 100 kt WC, 30%	A1	C2	C3	B3	C4	B1	B1
1b	Three 100 kt WC, 30% with Gd	A1	B1	B2	B3	A1	B1	B1
2	Three 17kt LAr, 4850', γ trig	A1	E5	A1	B4	E5	B1	E5
2a	Three 17kt LAr, 300', no γ trig	A1	E5	A2	B4	E5	B1	E5
2b	Three 17kt, LAr, 800', γ trig	A1	E5	A2	B4	E5	B1	E5
3	Two 100 kt WC, 15% + One 17 kt LAr, 300', no γ trig	A1	D4	B4	A2	D4	B3	D3
3a	Two 100 kt WC, 30% + One 17 kt LAr, 300', no γ trig	A1	D3	B4	A1	D4	B3	C2
3b	One 100 kt WC, 15% + One 100 kt WC, 30% & Gd + One 17 kt LAr, 300', no γ trig	A1	C3	B3	A1	B2	B3	C2
4	Two 100 kt WC, 15% + One 17 kt LAr, 800', γ trig	A1	D4	B4	A2	D4	B2	D3
4a	Two 100 kt WC, 30% + One 17 kt LAr, 800', γ trig	A1	D3	B4	A1	D4	B2	C2
4b	One 100 kt WC, 15% + One 100 kt WC, 30% & Gd + One 17 kt LAr, 800', γ trig	A1	C3	B3	A1	B2	B2	C2
5	One 100 kt WC, 30% & Gd + Two 17 kt LAr, 300', no γ trig	A1	D4	A2	B2	B3	B3	C2
6	One 100 kt WC, 30% & Gd + Two 17 kt LAr, 800', γ trig	A1	D4	A2	B2	B3	B2	C2

TABLE XXIX. Summary of the relative impact of the reference far detector configurations on the measurement sensitivity. Only topics where LBNE will make a competitive measurement are included. The entries consist of two parts: 1) a letter from A-E indicating the impact of the LBNE measurement made possible by a particular configuration as compared to the [expected] state of world knowledge, and 2) the relative ranking of the different configurations for the physics topic of interest. Highlighted boxes indicate the preferred option for that topic.

- With preliminary costs and draft CDR from the Project Team, an LBNE Executive Committee Retreat 10-11 September, 2010 made several decisions:

- Based on a preliminary differential cost estimate for the deep (4850) versus moderate depth liquid argon option (>100$M), further work on this option is not justified.
- Better costing information, which should come in November, will present us with an opportunity to make a branch point in the water/argon considerations.
- The recommendation on Far Detector Configuration should be made on the timescale of CD-1. One possibility is to decide on the configuration of one detector first.

Extracted from EC Summary Report
At September 2010 LBNE Collaboration Meeting

- The NSB decision on DUSEL led to a need to rework costs assuming a DOE-led Far Site development. It also put increasing emphasis on prioritization of science goals and "Value Engineering"
- December 5-6, 2010 EC Retreat in New Haven:

  1. 200 kton "WCE" is the "right size" considering balancing costs and physics performance
  2. A "mixed technology" solution is preferred, if a funding cap is not considered
  3. A surface liquid argon detector option should not be pursued at this time

...so we now had three options

Case Studies

- At the January 2011 LBNE Collaboration Meeting at UCLA is was decided to pursue three options: 200 kton WCD at 4850, 34 kton LAr detector at 800, and a mixed technology solution that was TBD
- Case Study managers were appointed to do in-depth studies of the science capabilities of these options.
- The Project Manager initiated cost/risk/schedule studies of these options in parallel

- DOE OS decided to only pursue a far lab at the Homestake Site at this time. A committee headed by J. Marx and M. Reichanadter tasked to review LBNE as far as costs and science to aid them in making a decision whether to continue to pursue the Homestake option
- Case Studies were made for WCD-only, LAD-only, and Mixed Technology. The Mixed Technology option was seen by the Case Study managers to have the best physics, but very expensive compared to the single technology options.

- Due to interest in the 4850 option for potential impact on the field as a whole, and rising costs of the 800 foot option, the LAr 4850 option study was reopened in July 2011 by consent of the EC and Project Manager.
- Detailed Case Studies have now been developed for the WCD and LAD 800 foot options. LAD-4850/800 is seen mainly as a cost and risk (muon veto) issue and not central to technology selection (EC decision in summer 2011)

- Summer 2011, in a series of meeting the EC adopted documents outlining the principles and procedures for the final recommendation of the LBNE initial far detector configuration.
- A process that involves external and internal reviews that culminates in a recommendation was agreed to.
- First step was the science case study.

Full science agenda from WCD case study

Additional physics with ATM neutrinos not shown

Physics	Sensitivity	Workable Depth	Additional Requirements	Marginal Det. Cost
Beam ν_e appearance with 200 kt/700kW (2 MW), $5+\bar{5}$ years livetime				
$\theta_{13} \neq 0$	$\sin^2 2\theta_{13} > 0.007(0.004)$ 3σ, all δ_{CP}	800 ft	None	0
Mass Hierarchy	3σ resolution all δ_{CP}, for $\sin^2 2\theta_{13} > 0.04(0.01)$	800 ft	None	0
CP Violation	3σ discovery for 50% δ_{CP} range $\sin^2 2\theta_{13} > 0.03(0.01)$	800 ft	None	0
Beam ν_μ disappearance with 200 kt/700kW, $5+\bar{5}$ years livetime				
$\delta(\Delta m^2_{32})$	$\leq 0.013 \times 10^{-3}$ eV^2 (ν) $\leq 0.015 \times 10^{-3}$ eV^2 ($\bar{\nu}$)	800 ft	None	0
$\delta(\sin^2 2\theta_{23})$	≤ 0.005 (ν) ≤ 0.007 ($\bar{\nu}$)	800 ft	None	0
Non-Accelerator, 200 kt, 10 years livetime				
Proton Decay ($e^+\pi^0$)	0.6×10^{35} years	4300 ft	None	0
Supernova Bursts	30,000 events at 10 kpc	3850 ft	None	0
Solar ν Day/Night	0.5% on $A_{\rm DN}$	4300 ft	1.5× PMT coverage	\$50M
Supernova Bursts	IBD tagging	3850 ft	2× PMT Coverage Gd loading	\$120M
Relic Supernova $\bar{\nu}$s	9-50 events/yr 40 event bkd	4300 ft	2× PMT coverage Gd loading	\$120M
δ_{CP} (Daeδalus [1])	3σ discovery for 100% δ_{CP} range $\sin^2 2\theta_{13} > 0.004$	4300 ft	2× PMT coverage Gd loading	\$120M
Proton Decay ($K^+\bar{\nu}$)	1.0×10^{35} years	4300 ft	100kt scintillator	\$100M
Geoneutrinos	3770 events/year	4300 ft	100kt scintillator 1.5× PMT coverage	\$150M

Table 1–1: Summary of sensitivities for priimary physics and for additional physics made possible with enhancements to the detector configuration. Marginal cost column refers detector enhancement

Full science agenda from LAR case study

Parameter	Sensitivity	Depth Requirement	Comment/Assumption
Primary Objective 1.1. Beam measurements using ν_e appearance $5+5$ years livetime			
$\sin^2 2\theta_{13}$	> 0.008 (3σ)	minimal	all δ_{CP}
Mass Hierarchy	3σ for $\sin^2 2\theta_{13} > 0.05$	minimal	all δ_{CP}
CP Violation	3σ discovery for 50% δ_{CP} range	minimal	$\sin^2 2\theta_{13} > 0.03$
Primary Objective 1.2 Beam measurements ν_μ disappearance $5+5$ years livetime			
$\delta(\Delta m^2_{32})$ $(\nu/\overline{\nu})$	$\pm 0.016/0.025 \times 10^{-3}\, eV^2$	minimal	1σ, $\sin^2 2\theta_{23} = 1.0$
$\delta(\sin^2 2\theta_{23})$ $(\nu/\overline{\nu})$	$\pm 0.006/0.009$	minimal	1σ, $\sin^2 2\theta_{23} = 1.0$
Primary Objective 1.3. Nucleon Decay, 33 kt, 10 years livetime			
$\tau/BR(p \to K^+\nu)$	0.4×10^{35} years	160m	6–7 × beyond exp. SK limit
$\tau/BR(p \to e^+\pi^0)$	0.2×10^{35} years	16m	probably not competitive
Primary Objective 1.4. Supernova Burst, 33 kt, 10 years livetime			
Neutrino Yield	3,000 events at 10 kpc	160m	

Table 1–1: Summary of physics sensitivities for primary physics objectives with the LAr40 Far Detector configuration described in this report.

Additional physics with ATM neutrinos not shown

Science Capability Review

The Scientific Capabilities Review Committee is asked to evaluate and compare each of the two approaches to building LBNE with respect to its capabilities to achieve the science goals of the experiment. The Committee's review should consider, but not necessarily be limited to, the following questions:

1. What are the crucial assumptions made by proponents in deriving the sensitivity for fulfillment of the science goals?
2. How well are these assumptions justified by the proponents based on extrapolation from existing experiments, test beam measurements, and/or validated simulations?
3. How well have the proponents considered consequences of detector performance being degraded from the assumptions by "reasonable" variations, where "reasonable" is determined from experience with similar detectors?
4. Are there major scientific risks and opportunities that are not covered sufficiently in the Case Studies?

Review Committee:

- David Wark *(Imperial College/RAL)* **Chair**
- Paul Grannis *(Stony Brook)*
- Dan Green *(FNAL)*
- Ko Nishikawa *(KEK)*
- Hamish Robertson *(Washinton)*
- Bernard Sadoulet *(Berkeley)*

https://indico.fnal.gov/conferenceDisplay.py?confId=4900

Reviews in preparation for FDTD, and CD-1

- We have gone through two serious reviews already: 1) NRC review of underground science, 2) Marx/Reichanadter review of options for Underg. Sc. These were prepared by collaboration/project teams.

	Event	Location	Date
☑	Far Site Risk Analysis Workshop	Fermilab	13-14 October 2011
☑	Near Site Risk Analysis Workshop	Fermilab	19-20 October 2011
☑	Near Site Internal Conceptual Design Review	Fermilab	1-3 November 2011
☑	Science Capabilities Review	Fermilab	3-5 November 2011
☑	WCD, LAr, Beamline, Near Detector, Project Risk Mitigation Workshop	Fermilab	16-17 November 2011
☑	Conventional Facilities Risk Mitigation Workshop	Fermilab	21 November 2011
☐	Far Site Internal Conceptual Design, Cost, Schedule and Risk Review	Fermilab	6-9 December 2011
☐	Executive Committee Retreat	Lake Geneva, WI	12-14 December 2011
☐	LBNE Collaboration meeting	Argonne National Laboratory	15-17 December 2011
☐	Configuration selection		December 2011
☐	Near Site Internal Cost, Schedule and Risk Review	Fermilab	11-12 January 2012
☐	Director's CD-1 Design, Cost, Schedule and Management Review	Fermilab	February 2012
☐	DOE CD-1 Review		March 2012

Case studies preparation

Beam configuration decision

CDR and cost/sch prep.

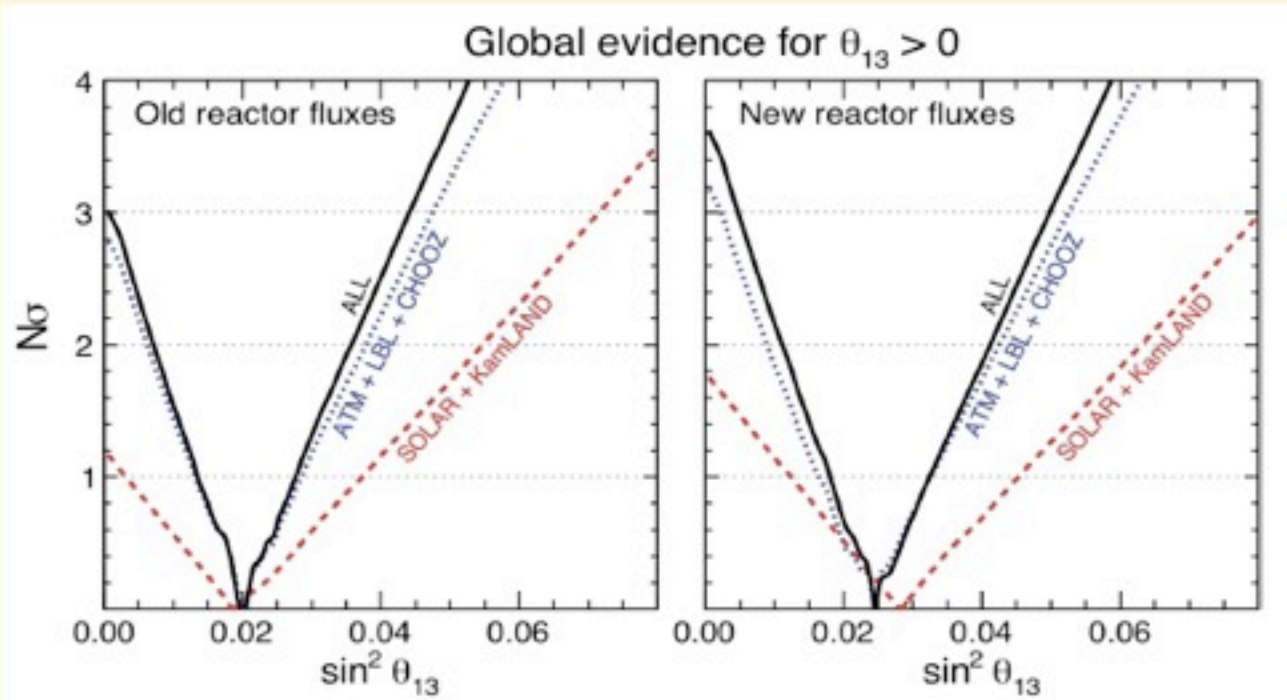
Case study documents prepared for Marx/Reichanadter review.

Review status

- Draft Reports from the Science Capability Review and the Far Site Cost and Schedule have been delivered.
- They are being deliberated on by the Project Management and Collaboration boards.

Scientific Outlook for Oscillations

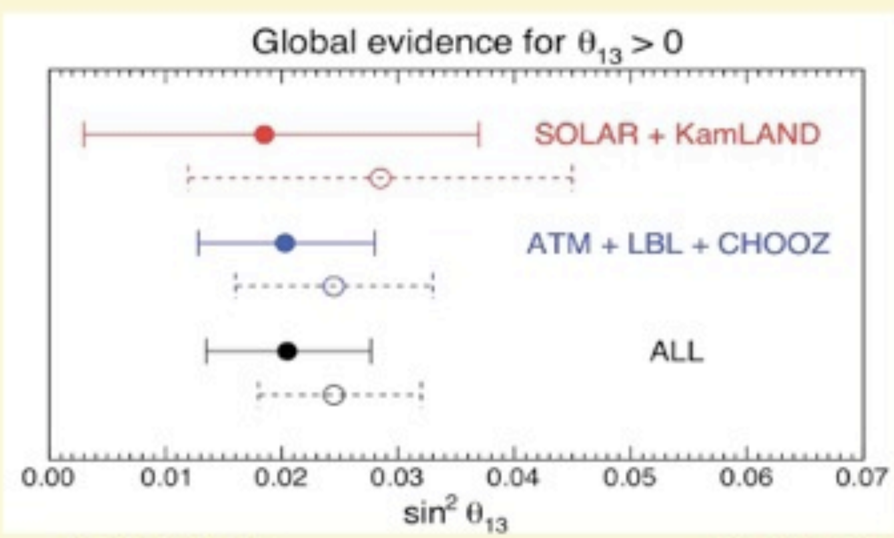
Our global results for $\sin^2\theta_{13}$ PRD 84, 053007 [arXiv:1106.6028]



Note:

ATM+LBL+CHOOZ now more significant that Solar+KamLAND

Astonishing conspiracy of the two totally independent sets of data



$\sin^2\theta_{13} = 0.021 \pm 0.007$ (old reactor fluxes)

$\sin^2\theta_{13} = 0.025 \pm 0.007$ (new reactor fluxes)

In conclusion, evidence for $\sin^2\theta_{13} > 0$ at $> 3\sigma$ (with small changes for new/old reactor fluxes assumed in the fit).

We shall use $\sin^2 2\Theta_{13} \sim 0.1$ for illustrative spectra

Detector Size Considerations

$\sin^2 2\theta_{13}$	Signal evts 0CP, (+)	Events 0CP (-)	Events 90CP (+)
0.02	170	70 (0.41±0.06)	234 (0.16±0.05)
0.04	320	132 (0.41±0.04)	415 (0.13±0.04)
0.1	774	325 (0.38±0.03)	923 (0.088±0.024)

- Table for neutrinos only. Asymmetry in brackets.
- 100 kTon*yr of efficient mass needed for 3 sigma CP resolution.
- Anti-neutrino running and spectrum analysis needed for ambiguity resolution.
- Hierarchy resolution improves with Θ_{13}

A = (N-M)/N+M).
dA = Sqrt((1-A^2)/(N+M))

For CP violation detector mass cannot be tuned for Θ_{13}

- Use 0.7 MW.yr.100kTon (eff mass)
- Efficiency will be defined with respect to total CC cross section.
- Efficient mass = Fiducial mass * signal efficiency.

Spectra from WCD

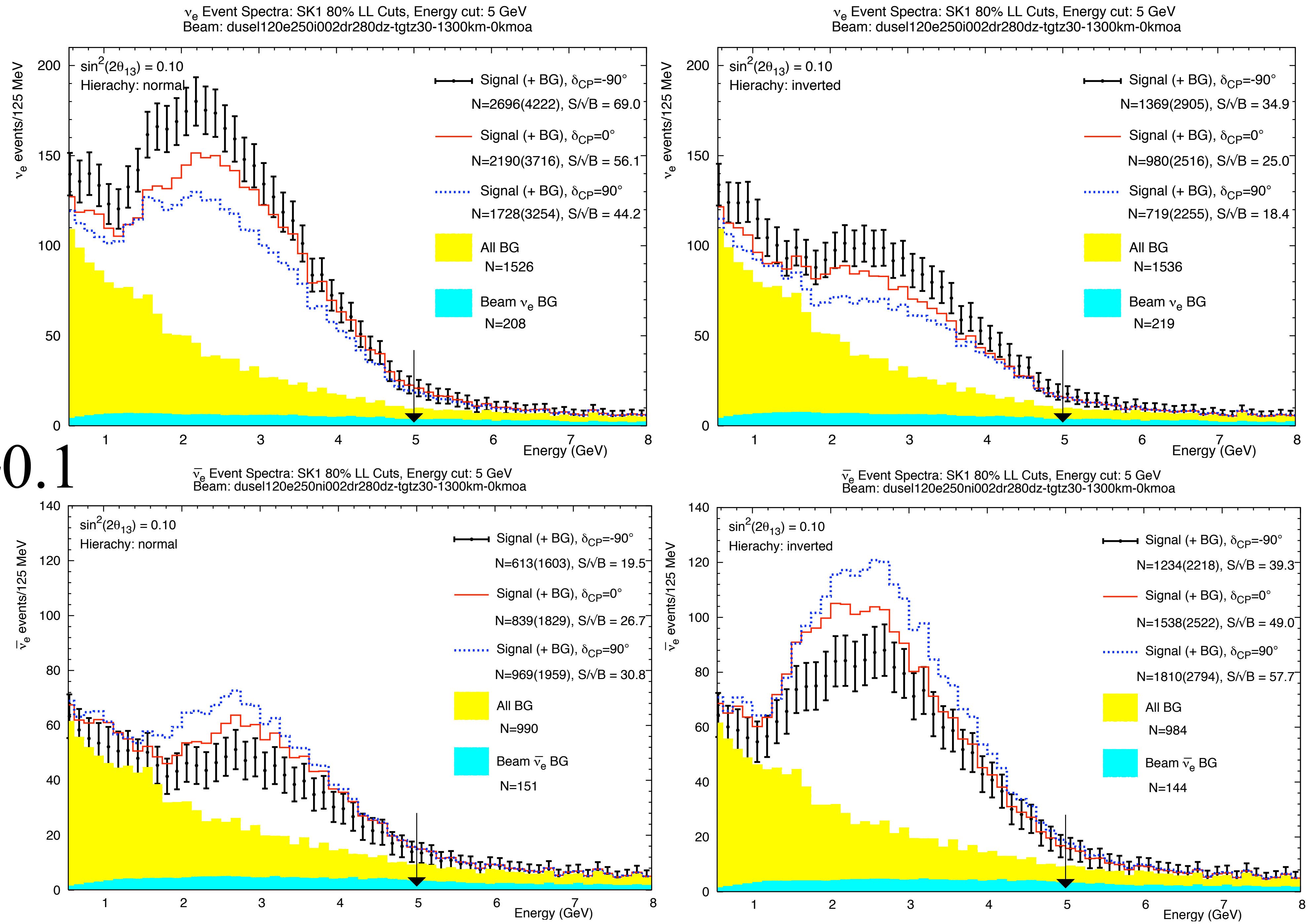
Normal

Inverted

Neutrinos

$\sin^2 2\Theta_{13} \sim 0.1$

Anti-nus

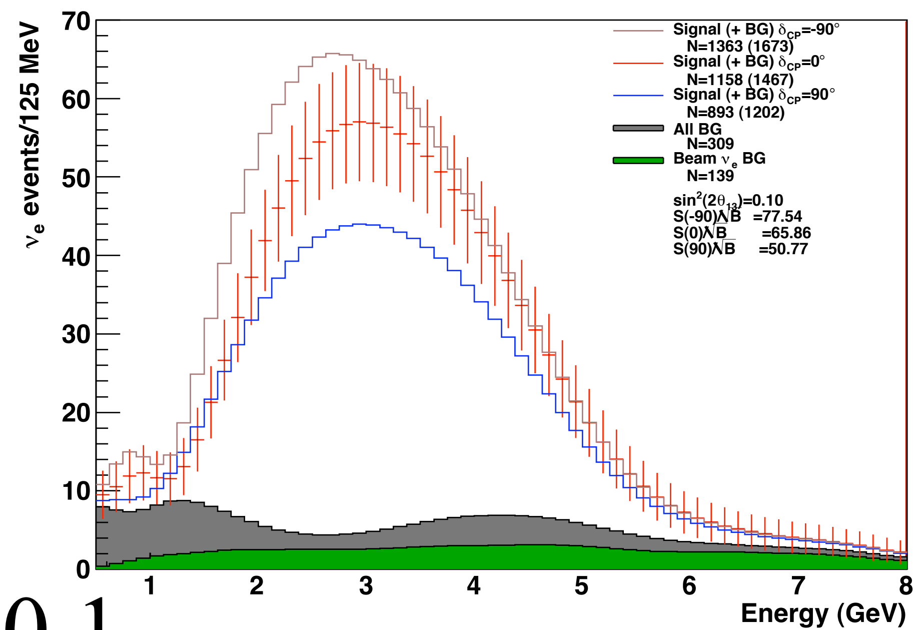


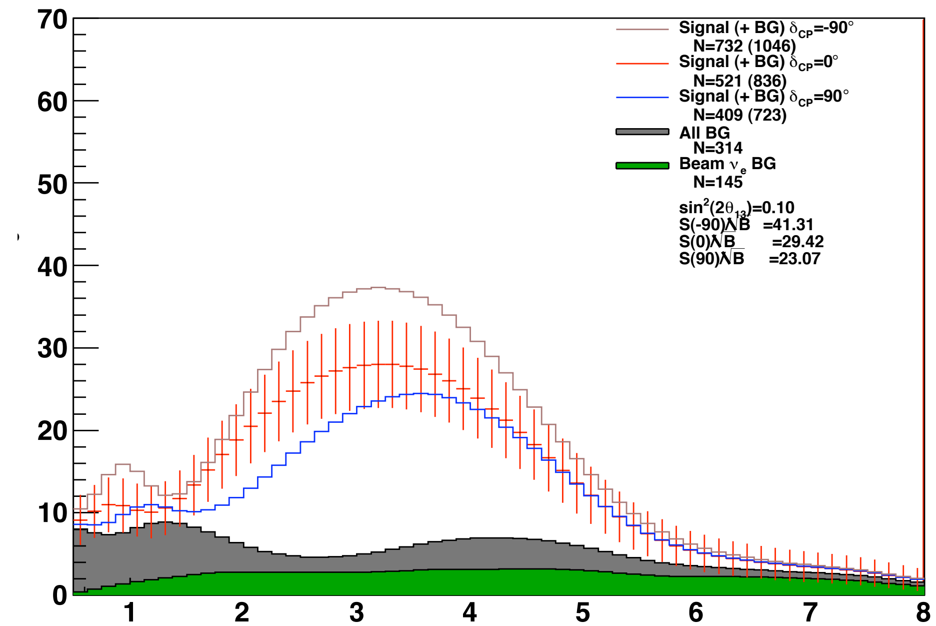
- For large signal, cuts can be loosened to admit more signal.
- Work continues to understand the background and signal.

Spectra from LAR

Normal | Inverted

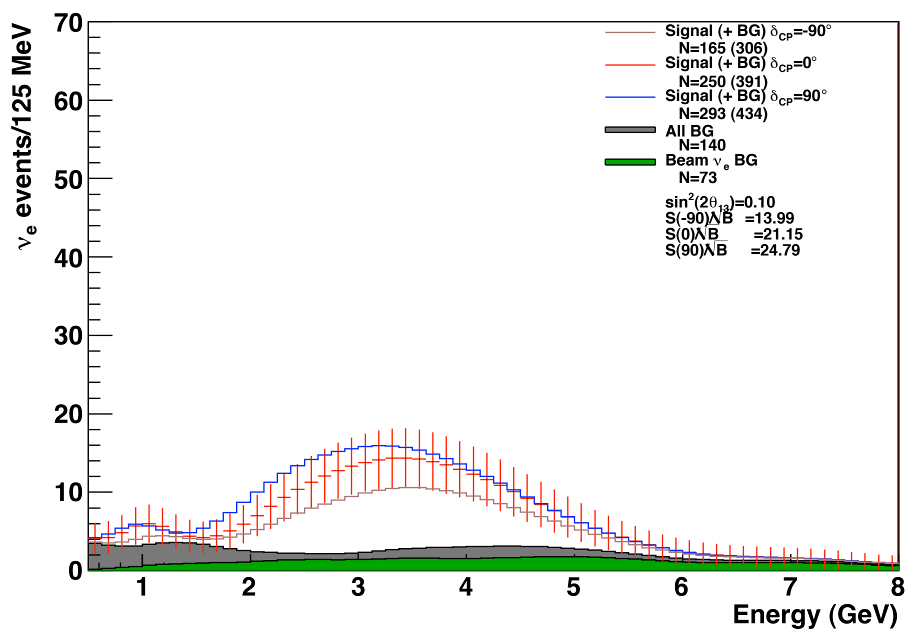
Neutrinos

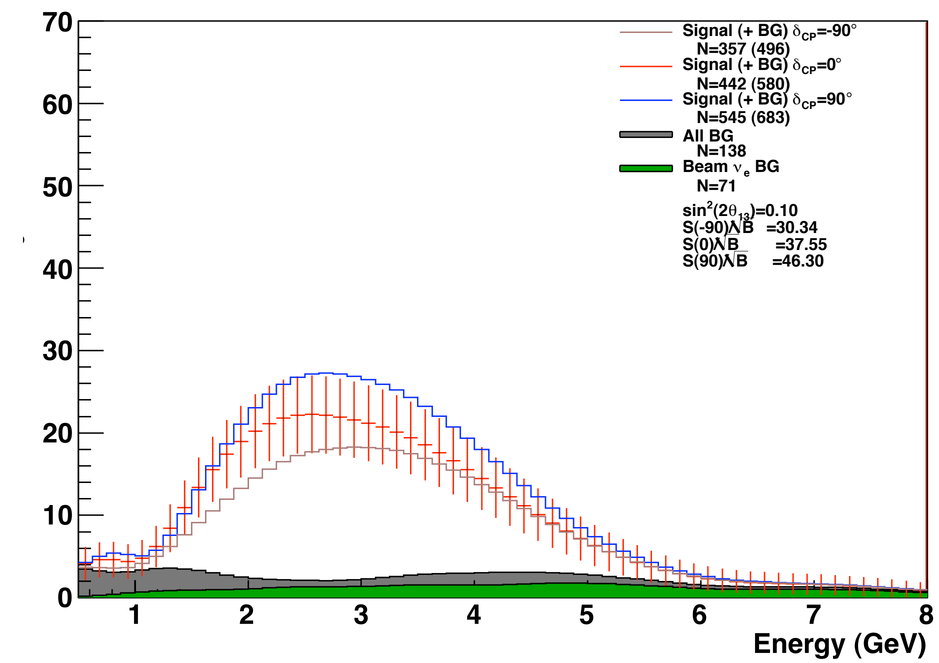




$\mathrm{Sin}^2 2\Theta_{13} \sim 0.1$

Anti-nus

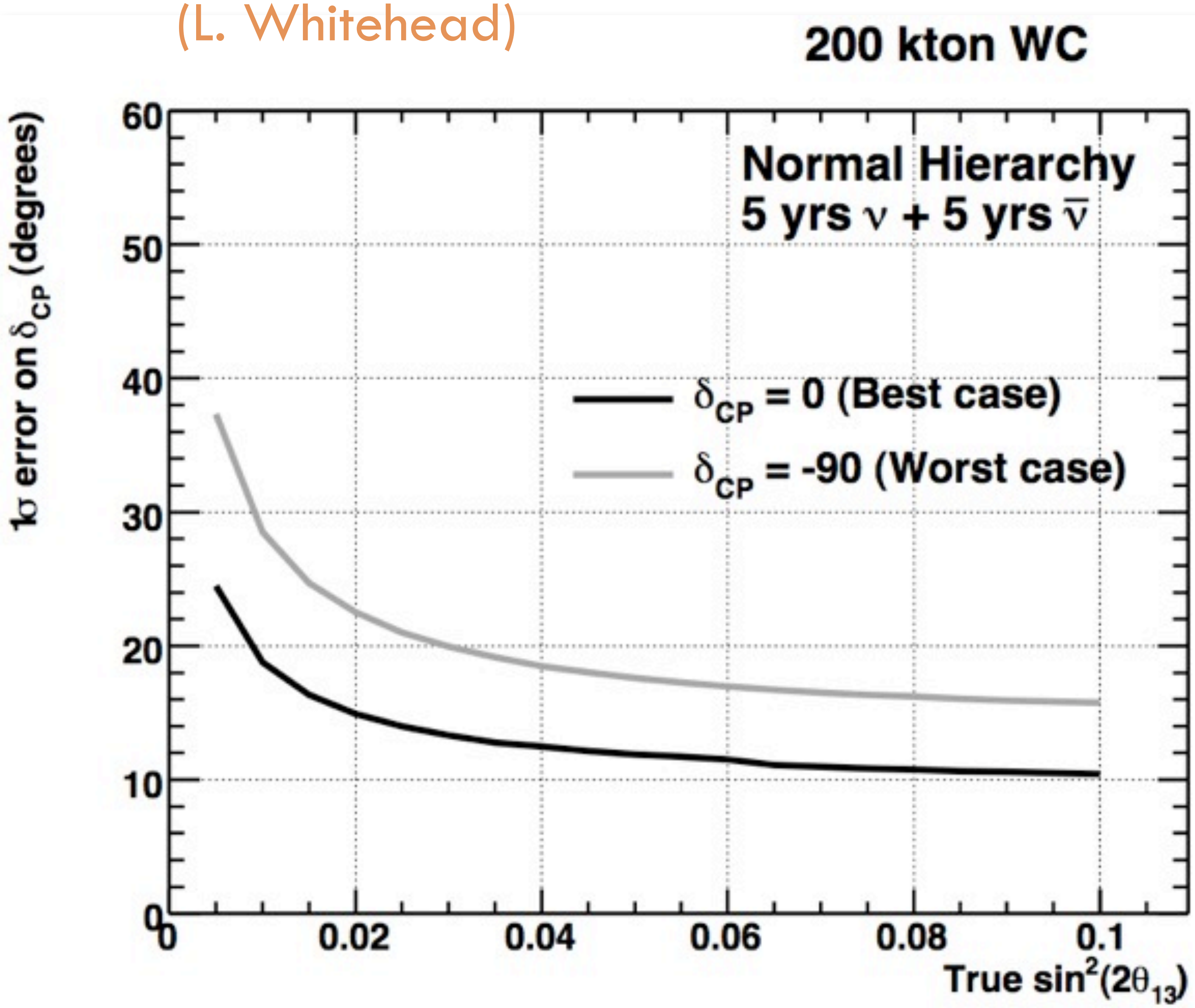




- LAR has higher efficiency at higher energies.
- Work continues to understand the background and signal.

Measurement of CP Phase

(L. Whitehead)



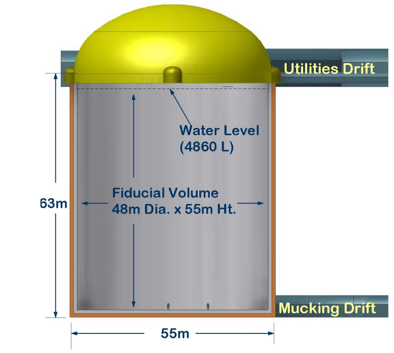
(calculation includes backgrounds, background uncertainties, and matter effects) ref: PWG2010

- The error on the CP asymmetry and thus how well can measure δ_{CP} is essentially independent of the value of θ_{13}

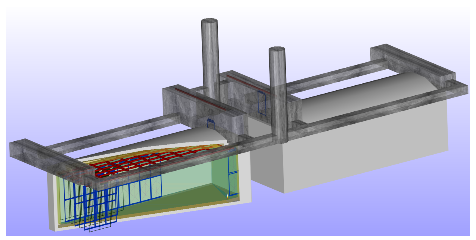
- can provide an excellent measurement of δ_{CP} over a broad range of θ_{13}

(10-20^0 for $\sin^2 2\theta_{13}$~0.03-0.10)

Technical Progress



- For the neutrino beamline a careful evaluation of two alternatives was performed. Evaluation included technical risks, radiation issues, costs, and schedule.
- The technical boards made a difficult choice to go with MI-10 extraction and an above ground beam.
- The liquid argon purity demonstrator (LAPD) has achieved several ms lifetime milestone.
- Significant development on new photomultipliers has taken place from two vendors.

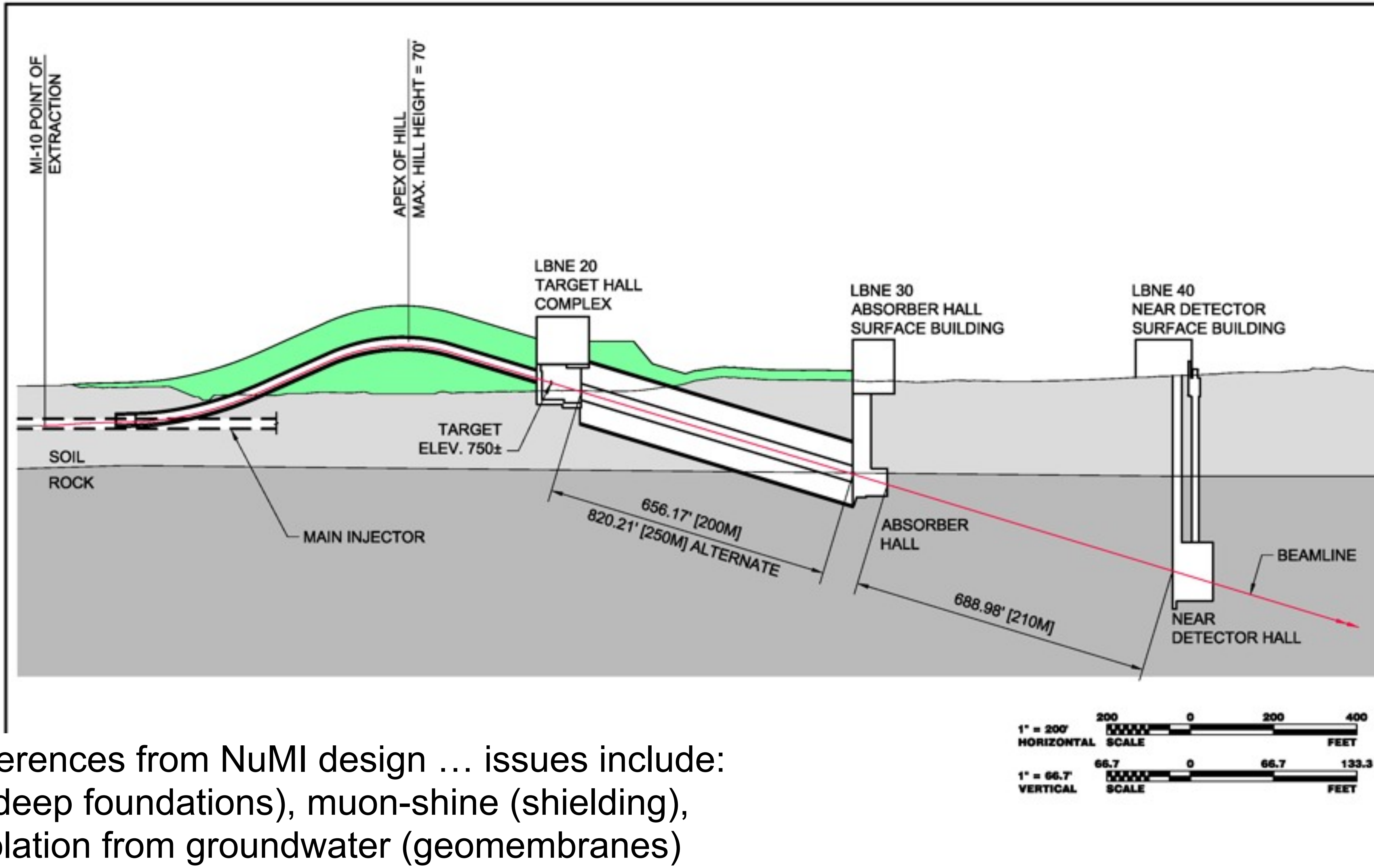


Neutrino Beam Alternate Designs: MI-10 Extraction, Shallow Beam

Neutrino Beam Alternate Designs: MI-10 Extraction, Shallow Beam

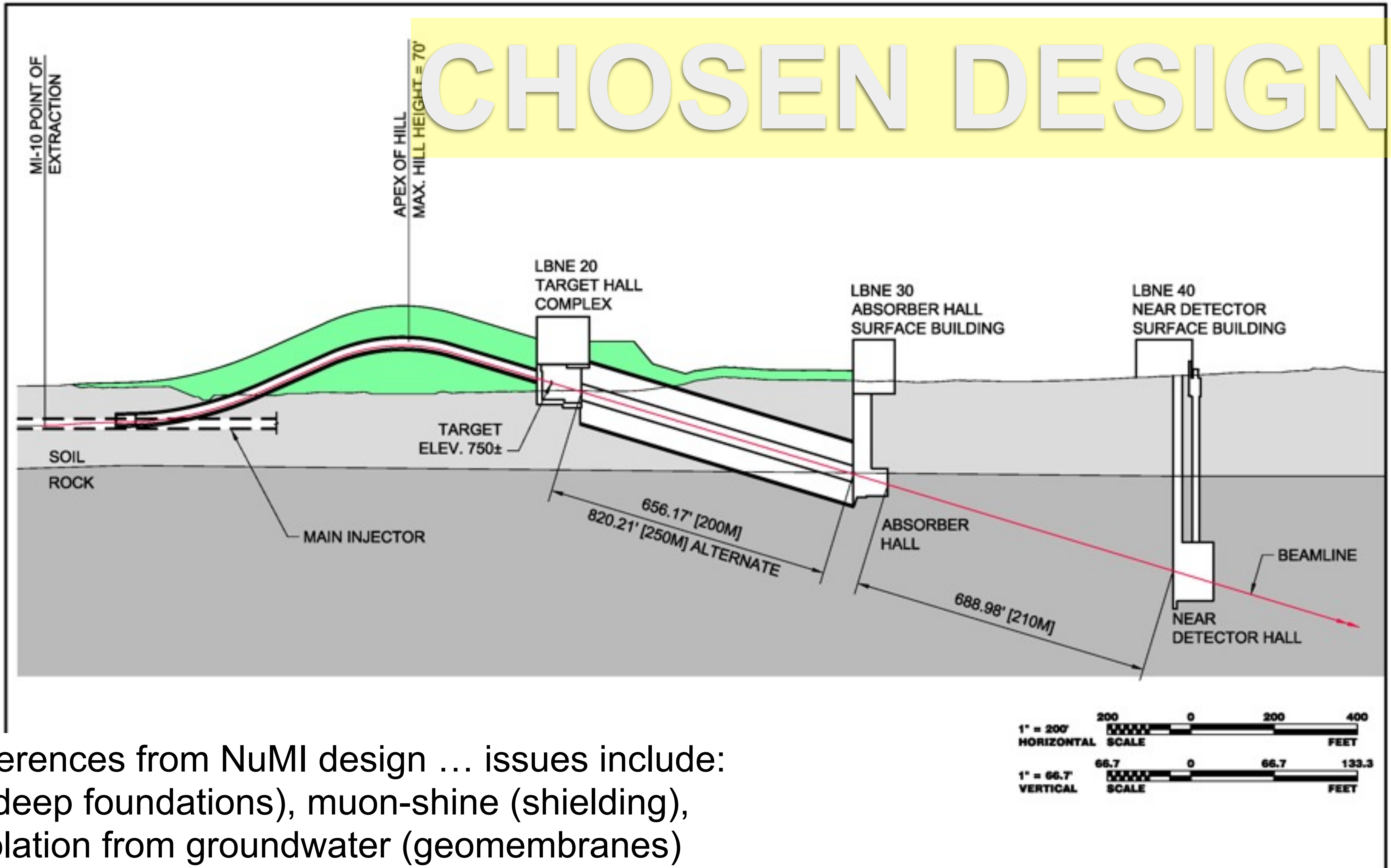
CHOSEN DESIGN

MI-10 Extraction, Shallow Beam



Many differences from NuMI design … issues include: stability (deep foundations), muon-shine (shielding), tritium isolation from groundwater (geomembranes)

MI-10 Extraction, Shallow Beam



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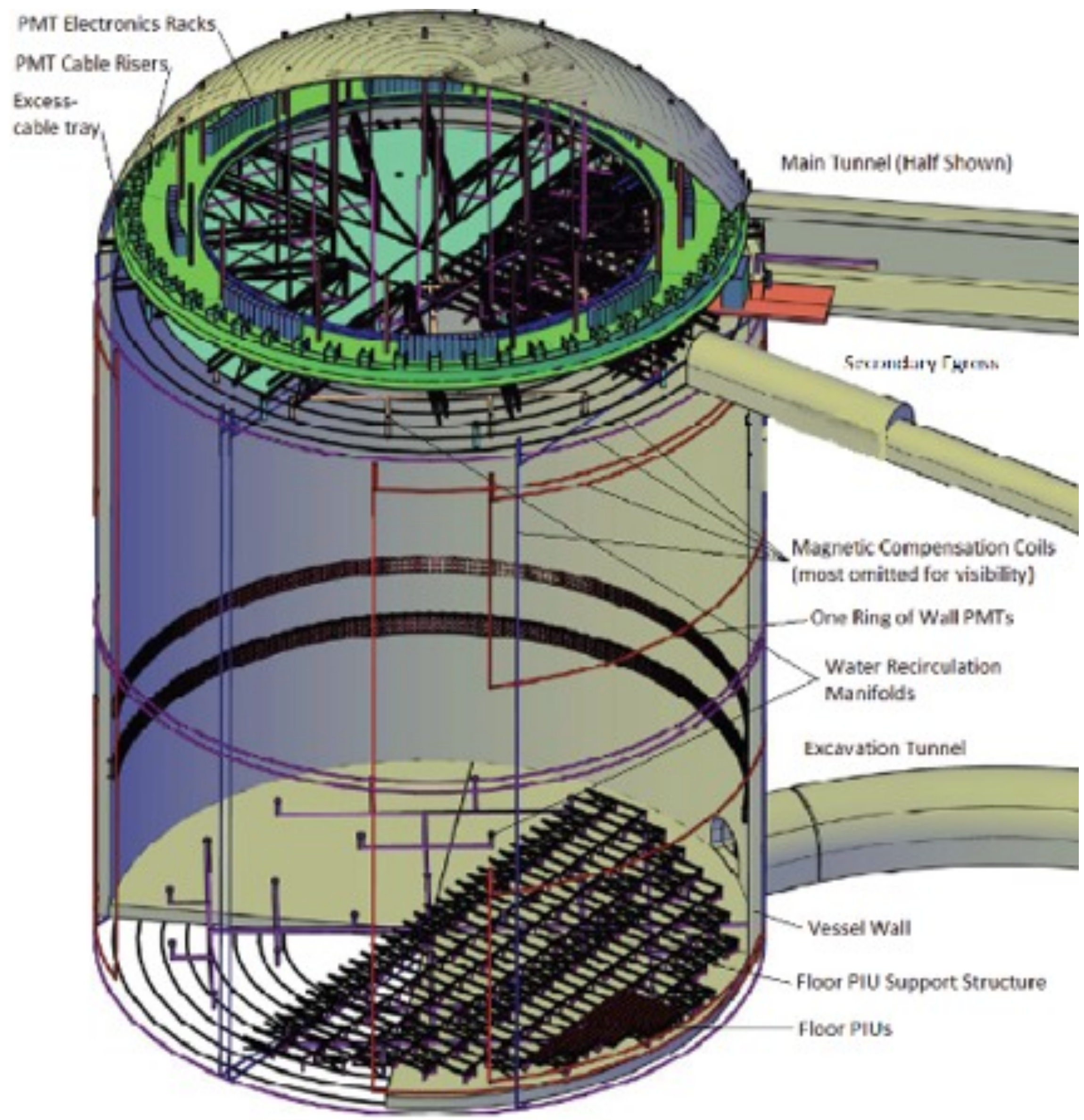
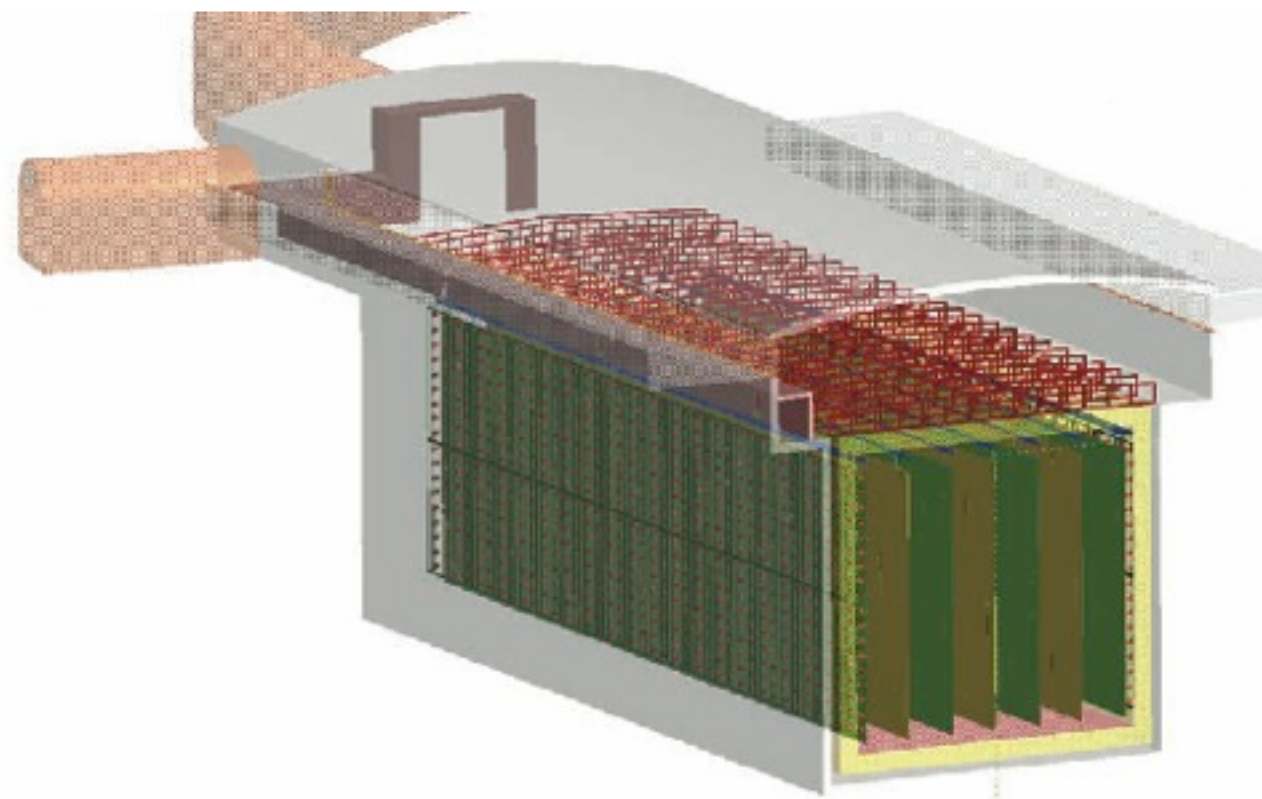
Detector Designs

200 kT water Cherenkov



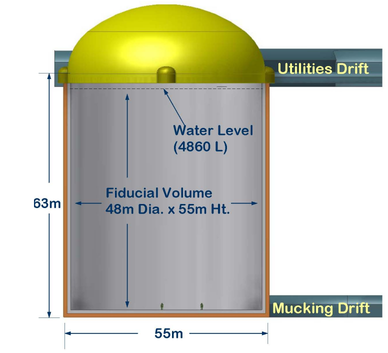
One 200 kT fiducial WC detector
Located at the **4850 foot level (0.2-0.3 Hz)**

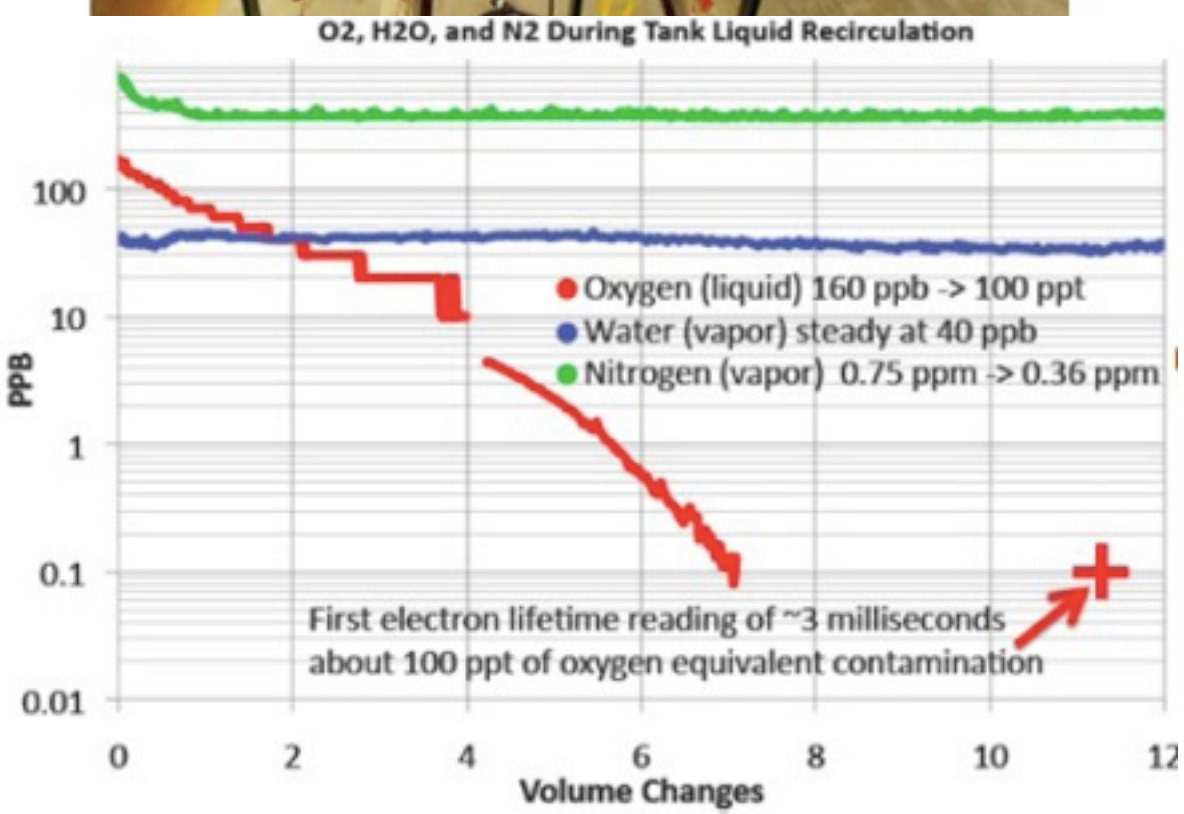
34 kT liquid argon



Two 17 kT fiducial LAr detectors
To be located at a new drive-in
site at **800 foot level or at 4850**. (one
detector shown here) (~200 Hz at 800ft
0.13-0.2 Hz at 4850ft)

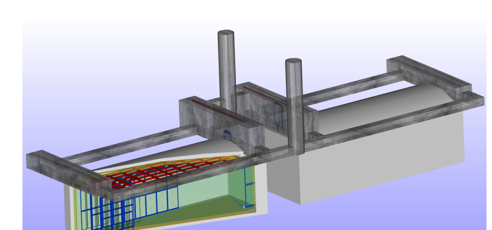
LAPD progress



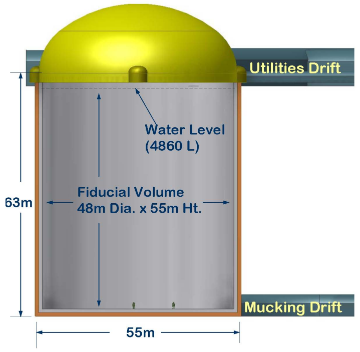


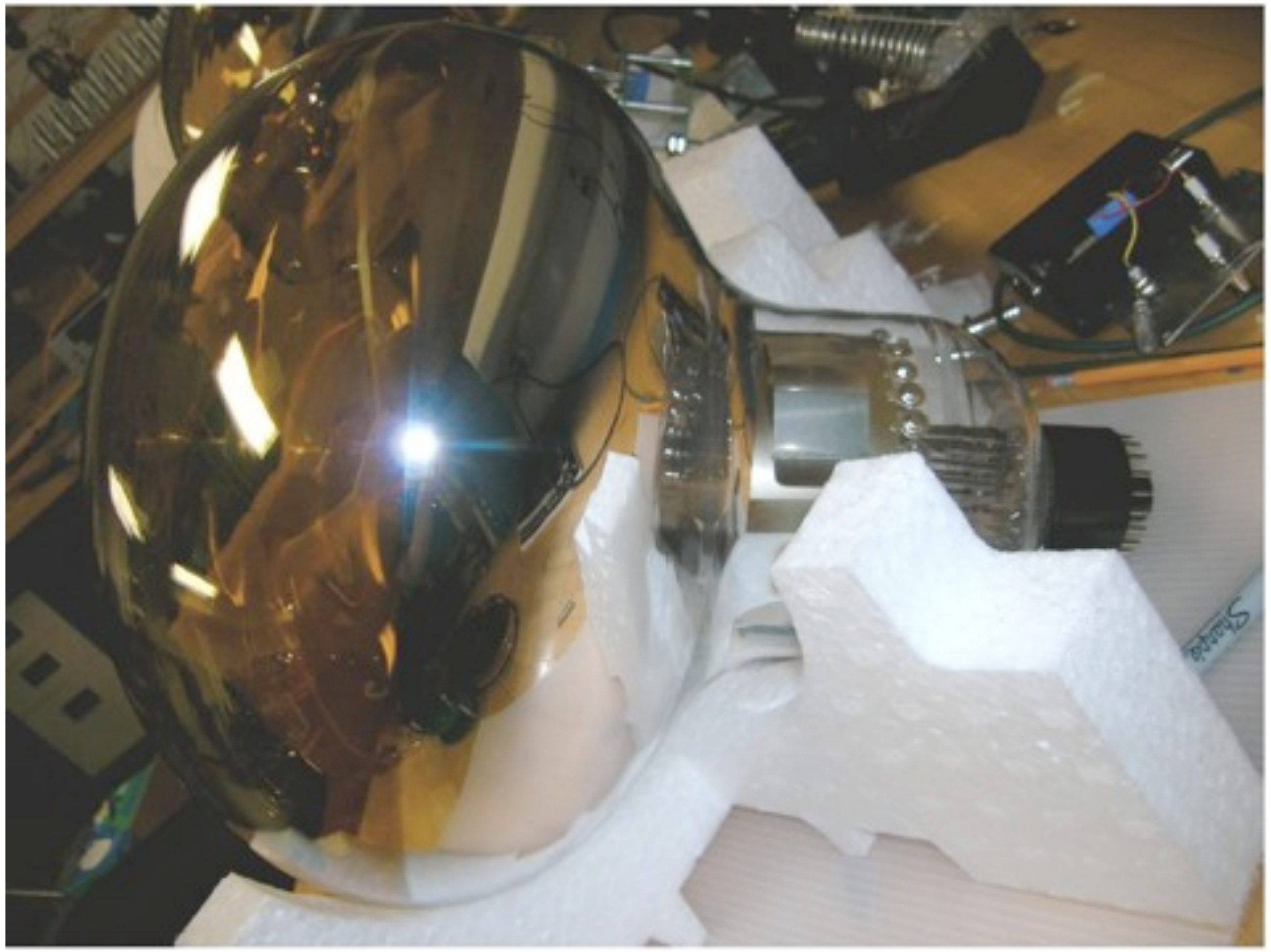
- Argon gas piston purge technique has been tried to achieve LAR purity.
- Stable electron lifetime of >3 ms has been demonstrated without cryostat evacuation.

From Brian Rebel

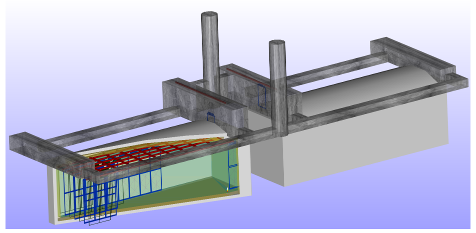


Water Cherenkov Progress

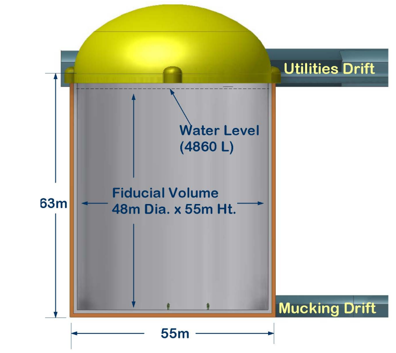




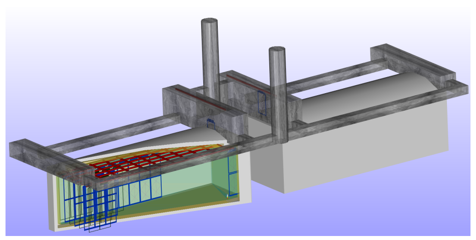
- HPK has developed 12 inch HQE PMT with 11 bar pressure capability.
- ADIT/ETL is developing an 11 inch PMT with similar parameters.



Conclusion



- In 2008 P5, this PAC, HEP community, FNAL, and DOE made an important and courageous decision: to pursue a world class neutrino program with a vision for a large detector underground and a high intensity beam.
- Recent progress in neutrino physics suggests that the investment we made has a high probability of success.
- We are currently years ahead of anyone else in planning for an experiment such as LBNE.



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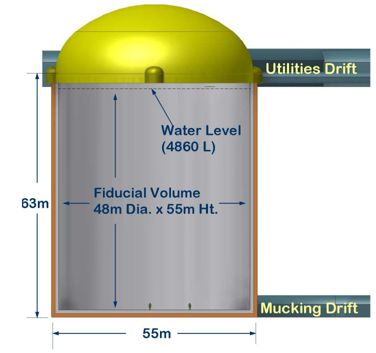

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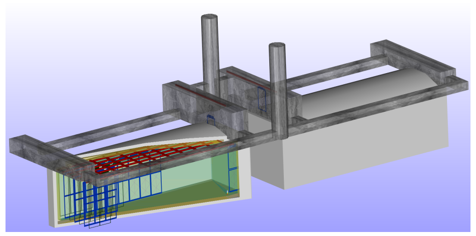
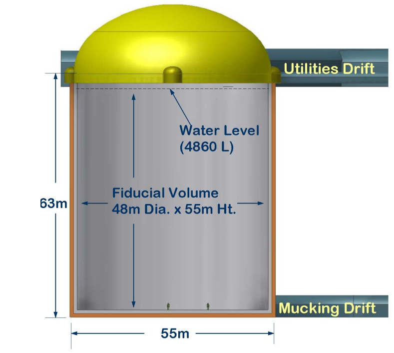
GREAT SCIENCE AHEAD





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